Light and Human Vision Based Simulation Technology

Jacques DELACOUR, Optical Engineer, Founder & CEO, OPTIS
ZE La Farlède, BP 275
83078 Toulon Cedex 9
France

jdelacour@optis.fr

ABSTRACT

Sight is the most important sense in the decision-making process: 85% of the information we receive comes from what we see.
Traditionally, simulators aim to focus on reproducing critical situation as best as possible. They are more focused on representing the 3D environment when moving than real perception of the scene. Faithfully simulating visual perception is the goal of the technology presented in this paper.
Thanks to two research and development projects, in simulators and in realtime visualization, both applicable in virtual reality centres, company OPTIS is developing an advanced true visual rendering technology, developed to be used in the design of new systems and for training purposes. The aim of the technology is to reproduce, on a display and in a virtual reality centre, the visual perception that a human would have of a scene in real life.
It is the first time a simulator is treating all lighting effects including ultraviolet and infrared band, encountered in a scene. Targeted effects include, but are not limited to, natural lighting, human machine interfaces, reflections on windshields and materials, display emission, infrared observation, street lighting, opponents and moving targets.

1.0 INTRODUCTION

Designing a realtime simulator requires high speed calculations to provide images, sometime stereoscopic, to the operator. Realistic rendering images are important for ensuring that the trainee behaves authentically during the simulation: 85% of the decision is taken based on vision. In concrete terms, how can we really take a decision if we do not see the object we are supposed to see, because of the sun that dazzles you, or simply because of a reflection coming from a street light around you?

As in many domains of numerical simulation, having realistic behaviour requires adding physics models in the loop. Light, as well as optical simulation, is part of this and is often approximated to geometric perception without taking into account the energetic balance. Providing a correct image to the observer first requires a correct simulation of light emission, propagation and all effects that will not only be in the field of view but also around the observer.

Providing realistic images means going one step further, as the goal is to model the way the light will be perceived. It therefore requires the modelling of a human sense: vision. A correct model of the human eye requires the handling of linear and non linear functions, since human vision involves multiple sensors, with variable resolution, and effects such as glare which affect central and peripheral vision.

This paper describes the development of a new realtime technology integrating both light effects and human vision perception.

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14. ABSTRACT

Sight is the most important sense in the decision-making process: 85% of the information we receive comes from what we see. Traditionally, simulators aim to focus on reproducing critical situation as best as possible. They are more focused on representing the 3D environment when moving than real perception of the scene. Faithfully simulating visual perception is the goal of the technology presented in this paper. Thanks to two research and development projects, in simulators and in realtime visualization, both applicable in virtual reality centres, company OPTIS is developing an advanced true visual rendering technology, developed to be used in the design of new systems and for training purposes. The aim of the technology is to reproduce, on a display and in a virtual reality centre, the visual perception that a human would have of a scene in real life. It is the first time a simulator is treating all lighting effects including ultraviolet and infrared band, encountered in a scene. Targeted effects include, but are not limited to, natural lighting, human machine interfaces, reflections on windshields and materials, display emission, infrared observation, street lighting, opponents and moving targets.

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2.0 METHODOLOGY

2.1 State of the art

Traditionally, simulators aim to focus on reproducing critical situation as best as possible. They are more focussed on representing the 3D environment when moving than the real perception of the scene which is the goal of this new technology. This type of technology is strongly based on graphics shaders or the using of GPU libraries, which offer low level optical models of light sources and surface qualities.

In driving simulation, some systems are focused on night driving and virtual testing of headlamps enabling you to simulate the effect of light on a virtual road. They provide a field of vision of the lit road which is displayed on a large screen and sometimes several displays to enlarge the driver’s field of view.

Adding physics to simulators, however, requires the development of more accurate optical models both for light source emission and for light diffusion. This means it is necessary to rebuild a realtime algorithm able to handle full light propagation.

Going further, it is necessary to take into account human vision to simulate effects that projection systems can't reproduce because of their gamut and dynamic.

2.2 Goal of the project

What we propose with this new approach to simulators is to start from physical data to achieve a final accurate rendering allowing users to take decisions on the scene they are seeing. We will illustrate this, using different types of simulators in day and night conditions, for vehicles, aircraft, ship and land applications. The earlier we can detect a danger, the better it is for the design process.

The goal of the project described in this paper, is to develop a new simulator technology fully based on physics and the physiological perception of light, taking into account all the light effects which occur during operations. This simulator technology will be fully compatible with virtual reality centres.

2.3 A physics based approach to rendering

2.3.1 Energetic consideration

First, to make an accurate rendering, it is necessary to take into account the real energy in the scene. This requires spectral simulation. Most of the current real time simulators use a RGB spectrum approximation. However when looking at the rendering equation [1], it appears that reflected radiance computed with spectrum integration is different to the radiance computed with RGB approximation:

$$L_r(\theta_r,\varphi_r) = \int_{\lambda=0}^{+\infty}\int_{\theta=0}^{\frac{\pi}{2}}\int_{\varphi=0}^{2\pi} L_i(\theta_i,\varphi_i,\lambda)\rho(\theta_i,\varphi_i,\theta_r,\varphi_r,\lambda)\cos(\theta_i)\sin(\theta_i)d\theta_i d\varphi_i d\lambda$$

$$\neq \sum_{c\in\{R,G,B\}}\int_{\theta=0}^{\frac{\pi}{2}}\int_{\varphi=0}^{2\pi} L_i(\theta_i,\varphi_i,c)\rho(\theta_i,\varphi_i,\theta_r,\varphi_r,c)\cos(\theta_i)\sin(\theta_i)d\theta_i d\varphi_i$$

Where :

- θ is the angle between face normal and considered direction

- φ is the angle between face binormal and considered direction
- λ is the wavelength
- Lr is the reflected radiance (W.sr-1.m-2)
- Li is the incoming radiance
- $\rho(\theta_i, \varphi_i, \theta_r, \varphi_r, \lambda)$ is the BRDF.

In the night simulation with street lighting for example, it is particularly important because of the spectra singularity: most standard lamp used for street lighting and vehicle headlamps are emissive gas lamps which are usually ray spectra (High or Low Pressure Mercury or Sodium, Xenon, ...). LED light systems which are increasingly used today also present a relatively thin peak in the spectrum.

If you are in the presence of an object absorbing this spectrum ray you will have a wrong perception and contrast of this material colour and reflectance using a RGB approach.

Another advantage of spectral simulation is the ability to simulate near infrared camera perception and restitution. Today's tactical situations require the use of such a system to detect potential dangers arriving. The camera sensor acquires infrared wavelengths and converts it into an electric signal in order to display in a control area or on a head up display for instance. We can also simulate the ultraviolet part of the spectrum to enhance the visibility of white objects by night.

2.3.2 Light source emission

All light sources may be characterised by their emission spectrum and their intensity distribution. Both characterise the way the light source emits photons anywhere in space. The intensity distribution is normalized using IES format and is provided by the lighting supplier.

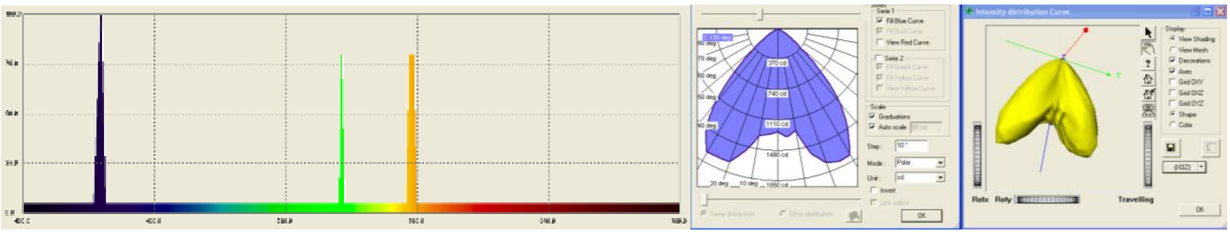

Figure 1: Left : OSRAM HP Hg Lamp ray spectrum (visible part) - Right : intensity distribution

2.3.3 Light/matter interaction

Going further, to be physically correct, we have to capture the spectral response of each surface reflectance by acquiring its real Bidirectional Reflectance Distribution Function (BRDF). This can be done using a spectral goniophotometer and the portable OMS² system. This BRDF has to fulfil the energy conservation law with an integral ≤ 1. This basic condition is not usually satisfied with standard real time BRDF models such as Phong shading model.

These measurements have been done for different types of material inside the scene (paint, metal, leather, apparel, signs ...) to enable visibility studies to be carried out.

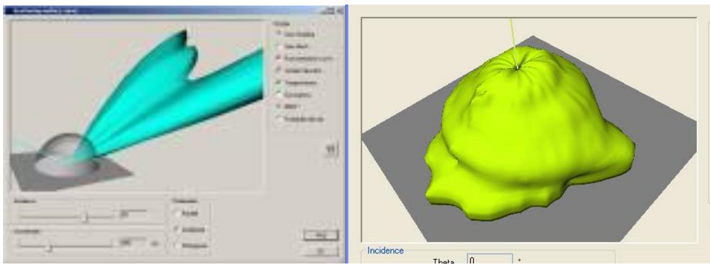

Figure 2: BRDF function represented for one wavelength / one incident angle

2.3.4 Light measurement

It is crucial to calculate radiance data as this correspond to what a human is sensitive to.

Indeed, the quantity of light coming back to the observer depends on the scene material (macadam, concrete) and if the surfaces are wet or dry. The perception of the environment can greatly differ depending on the light ambiance too. This effect is due to the fact that inside the eye, light is diffused by the surfaces and media encountered, before illuminating the retina. It is described by [2][3][4]. This stray light decreases sensitivity that may prevent the observer from identifying an important signal. That’s why our algorithm is able to handle a high variation of the level of luminance, like moon light and its reflection on the road, and sunlight.

In a vehicle, interior lighting with disturbing dashboard reflections in the windshield depends on the different surfaces involved in light propagation. As specular reflections change with the point of view, it is necessary to compute them in real time and allow the trainee to move his head inside the vehicle to avoid disturbing reflections. LCD displays must also be placed carefully inside the vehicle in order to avoid reflection and limit the glare effect on pilots. Head up displays and night vision goggles can be located inside the vehicle in order to adapt their luminance level. For all these cases, the choice of surface BRDF model and reliable physics algorithms is crucial in order to have an accurate estimation of the nuisance caused by these reflections. Thanks to this technology, using this information, even designers can adapt interior materials and colours to reduce and consequently avoid these phenomena.

The entire processing phase is done using physical units (watt, meter, ...) with floating point precision, using multi-core Central Processing Unit (CPU) and the high parallelism that the Graphic Processor Unit (GPU) offers as a 128 bit SIMD processor. Working on floating point values allows the production of High Dynamic Range (HDR) spectral images. The benefit of HDR images is now widely recognized for image production. The latest GPU improvements on shaders are used in our solution for colour evaluation. Computations are done at the pixel level to take into account sharp (thin gaussian for example) BRDF effects. For each source, we add the source contribution to the final rendering applying the corresponding BRDF for the observer direction, the considered source direction and spectrum. Using this method, we are no longer limited in the number of sources whereas OpenGL is usually limited to eight sources.

2.4 Modelling human vision

This process allows us to take into account the HDR image perception with human colour perception. A human vision model was developed in collaboration with worldwide specialists in visual perception to transform spectral luminance into perceived visual information. This model includes a day / night vision mode based on physiological aspects, and takes into account the eye’s response to light levels, colour, contrast, as well as rapid changes in surrounding luminosity. The human eye has a high range of luminance detection, able to detect luminance level from 10^{-6} cd/m² to 10^{8} cd/m². Projection systems used in a simulator don’t have such a high dynamic. So it is necessary to develop special functions better able to display the final image, as if the scene were seen by a human. To adapt the luminance level included in the HDR image to the screen used to display the result, we perform a compression taking into account human vision properties and namely these described in [5][6].

Sun and oncoming lights from an opponent cause glare for an observer. This glare reduces observer's perception of the contrasts of the scene and the displayed information. Higher intensity light around the observer (either coming from the surroundings or from a source such as street lighting) reduces glare experienced by the observer, as the contrast between ambient and oncoming light is reduced.

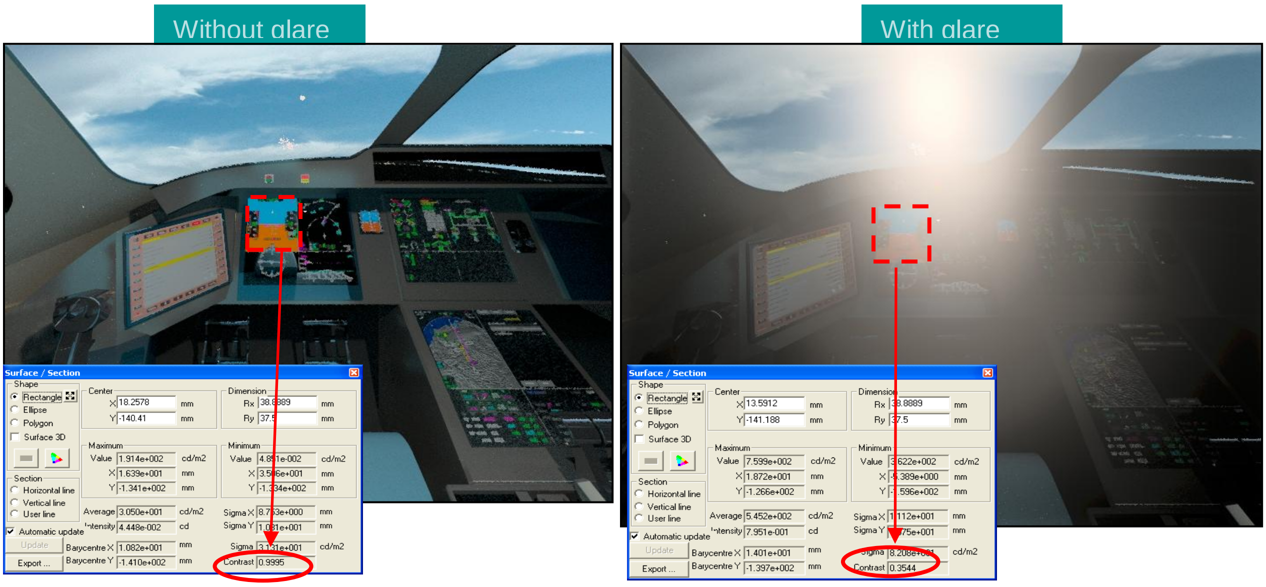

Figure 3: Simulation of glare effect due to sun. Being physics based, the software results are so reliable that measurements can be taken in the projected image.

In a vehicle or in a ship, increasing the level of interior lighting causes the equipment to be reflected in the windows which is also a distraction for the pilot- something designers want to avoid. By simulating the same scene using different interior lighting levels, the ergonomist will be able to use this application to find the best compromise between glare from opponents, and reflections of the equipment in the windows. This physiological model also integrates the fact that the optical performance of the human eye progressively declines with age [7][8]., causing loss of contrast sensitivity and acuity, increase in discomfort glare. The amount of light scattered into the different media of the eye increases with age [2]. Figures 4 illustrate this phenomenon.

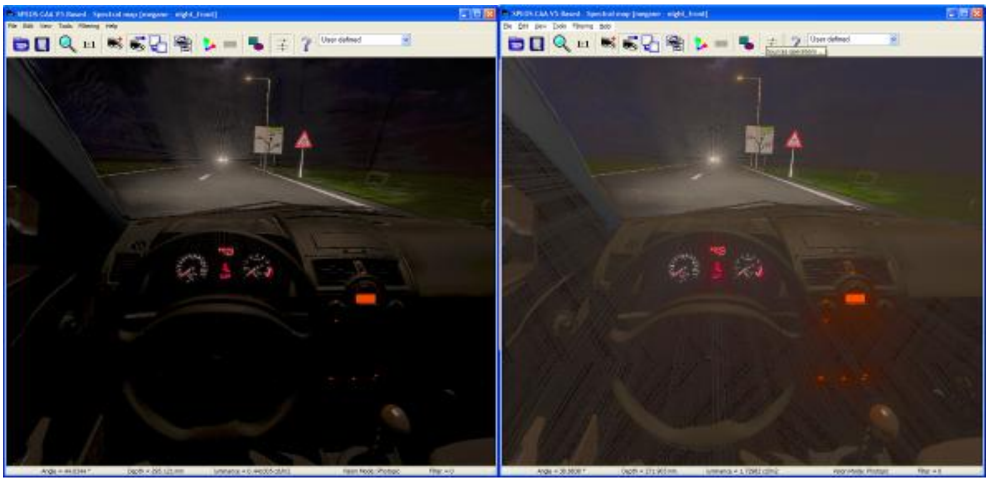

Figure 4: Simulation of the increase of light scattered by different media of the eye when driver age increase. Age of the driver is 20 on left image and 60 on right image.

This technology will soon take into account the temporal adaptation of the human eye. Indeed, the human visual system needs a release time before reaching the final stage of adaptation. The dark adaptation refers to how the eye recovers its sensitivity in the dark following exposure to bright lights. This type of adaptation is observed when an officer enters in a dark control room after receiving glare due to the sunlight. The light adaptation refers to how the eye recovers its sensitivity in the day following low light exposure, observed for example when an officer leaves a dark area.

At the end of the simulation process, with a view to addressing an RGB projection system, we compute the final RGB colour from the resulting spectrum. This computation is based on CIE standard observer functions to transform spectrum to XYZ colour space. This last step takes into account the ICC display profile to better match real colours. That way we can also compensate colour variation over the lamp's lifetime.

To improve the user's immersion, this graphic pipeline can be duplicated computing two different images, one for each eye in stereoscopic mode, using head tracking. Using an accurate BRDF model improves the realism as, for sharp BRDF, one eye can see a disturbing reflection while the other is not affected. This reflection behaviour improves the surface aspect rendering, which is the only information to address visual perception.

3.0 IMPLEMENTATION

The actual implementation of our simulator is based on Virtools. Virtools is a development platform allowing prototyping and industrial applications, it also manages integration with Virtual Reality Centres such as CAVE-like systems, Reality Centres, Workbenches, ... and also manages a wide range of VR devices (trackers, glasses, haptic systems, ...). Inside Virtools, the OPTIS rendering part is completely separated from the behaviour part. This separation allows the developer to manage all the interactions of the trainee with his environment and the user interface, to implement his own lighting strategy, to add new geometry, lights, change the lighting configuration, ... All the rendering information (sources intensity diagrams, source spectrum and BRDF) is transferred to the OPTIS rendering part in order to compute the resulting images in mono and stereo. Input files (intensity diagrams, BRDF, ...) are directly loaded into Virtools environment using new OPTIS Building Blocks inserted as a Virtools plug-in.

4.0 APPLICATIONS

4.1 Projectors validation

One application to be addressed is the use of light projectors to enhance vision, for instance helicopter trackers. This application allows the evaluation of light levels in a city and represents on a display what the pilot can really observe from his helicopter.

This also allows the light beam to be checked in static mode, and moreover evaluate illuminance levels everywhere, even on a 3D building.

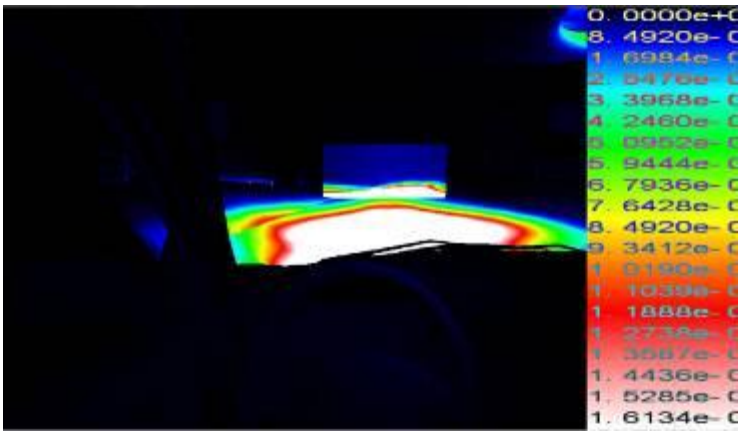

Figure 5: Irradiance level on the road and on a regulation plane.

Thanks to this simulator technology, engineers can validate tracking light systems. The orientation of light beams can be automatically calculated according to the position and movement of both the observer and target. Engineers can implement this tracking function inside the simulator to test it and check the lighting properties in different scenarios.

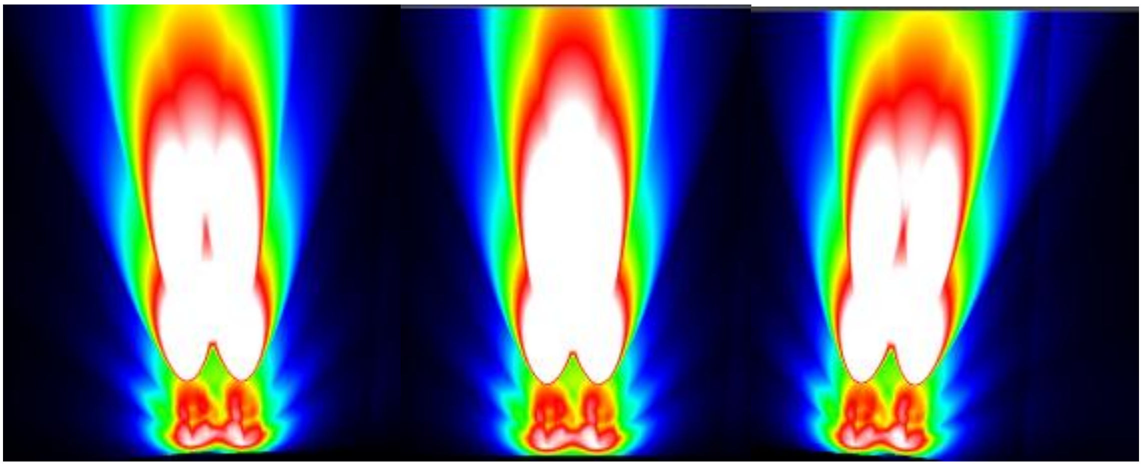

Figure 6: Light simulation (top view). Illuminance levels on the road surface.

4.2 Security and safety enhancements

Enhancements to night time safety and security are a goal for governments. This physics based simulator can help to improve safety on the road and security in a city checking new equipments such as safe jackets, road signs, road paints ... by taking into account the real behaviour of light reflection thanks to the use of an accurate BRDF function.

Figure 7: light reflectance (BRDF) applied on a virtual mannequin to check its visibility

The following application presents a 3D scene illuminated by the sun (Fig. 8), the moon (Fig. 9) and using night vision goggles by night (Fig. 10).

Figure 8: day scene of a city

Figure 9: night scene of a city **Figure 10: same scene by night wearing night goggles**

4.3 Optimize the ergonomy of a cockpit

As described previously, this technology can greatly help designers and ergonomists in their tasks. Designers can directly check the influence of surfaces and materials inside a vehicle and their behaviour in different lighting conditions. For instance common Sodium Lamp, Mercury Lamp, Tungsten reading lights, Zenith sun,... will all produce a different colour effect after reflection on the material covering the dashboard or on the instrument panel. The designer can virtually test in real time a plastic, leather, and brushed metal from his library and select the most appropriate one. This selection can be done both from an aesthetical point of view to enhance perceived quality and from an ergonomic point of view to avoid unwanted reflections that would disturb the pilot. It is particularly the case in night driving situations where each interior light can produce a reflection on the windshield or on side windows, but also during the day in the case of clear materials.

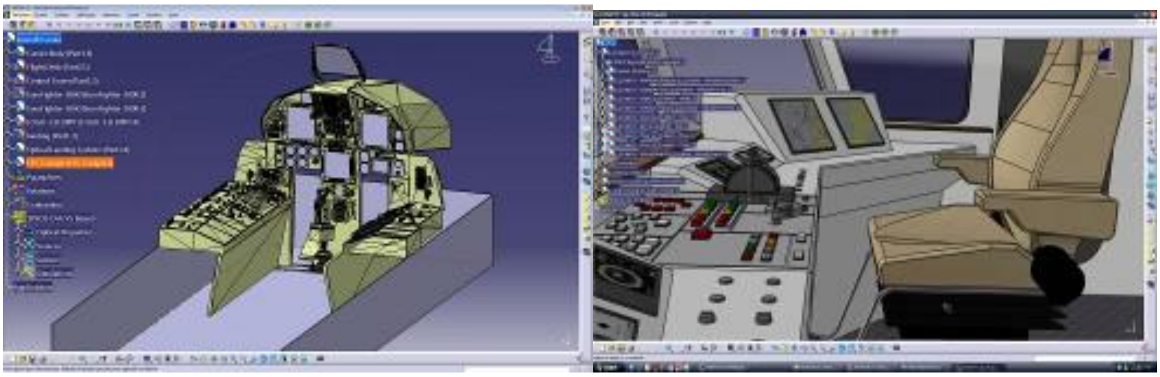

Figure 11: the cockpit may directly come from a 3D CAD CAM software allowing troops to be trained on a system which does not yet exist. Left : aircraft – Right : ship

Figure 12: Different light configuration can be selected and virtually tested during training

4.4 Performances

The current implementation of our simulator in a case of ten light sources, in high definition images (1920x1024) with spectral data and algorithm, with thirty (30) different BRDF files on an NVidia Quadro FX 5600 provide a twenty frame per second (20 fps) application reaching performances of traditional simulators.

5.0 CONCLUSION

The approach to vision simulation described in this paper is a new technology developed to improve simulators by displaying visual information as seen in real life. It offers an understanding of the visual perception of critical situations, allowing us to better train people: We mustn't forget that a human perfectly detects what he *expects* to see.

Consequently the human machine interface of any control system can be improved.

The photometric simulation part has been fully validated over more than ten years by worldwide users in optronics, lighting, display, automotive, aerospace, naval and consumer goods applications. This development was certainly a key to obtaining the light information essential for vision simulation. The results obtained with this vision simulation have been compared with success to common visual tests with a view to being validated.

The algorithm used enables us to simultaneously measure the impact of new technology lamps on the observer, and optimize the display design, the position and orientation of the display in a vehicle, taking into account all light effects inside the vehicle wherever the light is coming from, whether inside or outside.

This tool will also enable ergonomists and system designers to improve the conditions of global visibility, and in so doing the global perception of the environment that the observer will see by day and by night, whatever their age. Results provided include luminance (Cd/m²) perceived by the driver allowing also to check legibility using standard as CIE 145:2002 [9], MIL-STD-1472F or ISO 150008:2003.

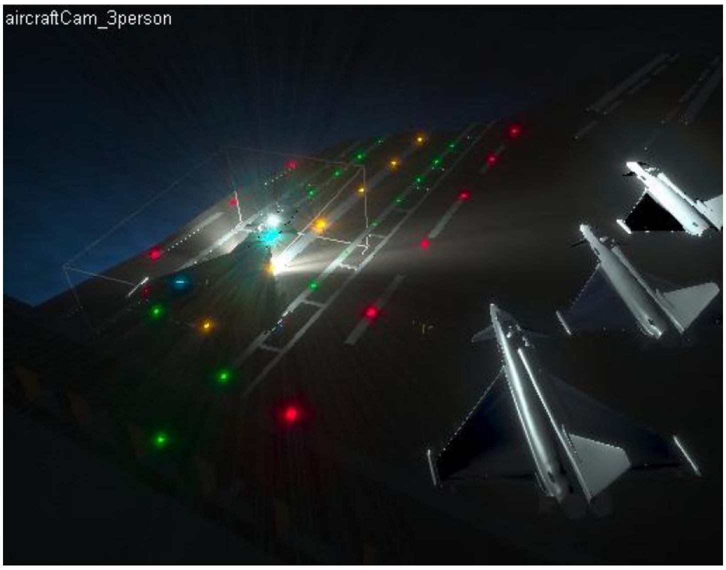

Figure 13: OPTIS landing simulation as seen from the control room with realtime glare effects

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Figure 14: Detailed view of glare effects showing sparkling and diffraction effects